Wurtzitic Boron Nitride On Diamond: The Ultimate Epitomical Wafer for Semiconductor on Insulator

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Abstract

In last four decades, the miniaturization of semiconductors devices (e.g. integrated circuitry) has been following Moore's Law with feature (e.g. transistors) density double in about every 18 months. This relentless geometrical progression would require the technological breakthroughs of many fronts such as UV photolithography with ever high frequency and nanom chemical mechanical planarization (CMP) with ever-small variations. However, with feature sizes of semiconductors entering the virus domain (10 to 100 nm), two physical barriers emerge that may not be surmountable with current wafer and substrate materials. These two barriers are stemming from the Second Law of Thermodynamics, i.e. entropy will increase along with the work performed in a closed system of semiconductor world. The entropy is the unwanted energy that may exhibit in random vibration of atoms, i.e. phonons (waste heat), and quantum fluctuation of charges, i.e. defects (intrinsic carrier).

The first barrier arises due to the accumulation of waste heat that cannot be effectively channeled out from the crystal lattice of Group IV semiconductors (e.g. Si, SiC) or III-V compound materials (e.g. GaAs, GaN). Semiconductors have thermal conductivities that are only a fraction of copper metal (about 400 W/mK) so it is now chilled by copper heat spreader. However, with the power density increasing beyond 2 watts/mm2 for the next generation chips, copper heat spreader will become a reservoir for heat accumulation rather than a river for heat transfer.

The second barrier arises due to the accumulation of charge carriers (electrons and holes) that are intrinsic to quantum fluctuation. These noisy charges will obscure the processed signal of electrical current. Moreover, the higher the temperature of the operating semiconductor, the more uncertain is the transmitted message. Eventually, the signal becomes unrecognizable or unreliable so the device will fail.

Both problems of phonon scattering and charge fluctuation can be reduced by increasing the bonding energy and by reducing its directional anisotropy of the crystal lattice. Diamond has the highest bonding energy with highest crystal symmetry of all materials. The strongest atomic structure allows diamond lattice to vibrate with the highest frequency, so it has the fastest sound speed (18 km/second) with the largest thermal conductivity (2000 W/mK). The strongest atomic structure also makes diamond lattice most stable even at high temperatures.

Consequently, diamond is the hardest and most rigid material with the lowest intrinsic carrier density. Diamond superlative structural stability is exhibited in its highest break down voltage for semiconductor applications.

The highest thermal conductivity makes diamond the ideal heat spreader. The lowest charge fluctuation makes diamond the dream barrier substrate. Hence, semiconductor on diamond (SOD) can be the best semiconductor on insulator (SOI) that is envisaged for making future ULSI, laser diodes, LED, microwave (MW) generators, and other signal processing or optic-electronic devices.

Recently breakthroughs of CVD diamond film deposition and polishing technologies have made diamond substrates engineering possibility rather than research curiosity. For example, Kinik Company is now offering diamond wafers up to four inches with a price comparable to commercial substrate materials (e.g. sapphire, silicon carbide). Moreover, the super smooth (e.g. Ra about 2 nm) polycrystalline film can be over coated with a submicron layer of hexagonal AlN that is preferentially oriented with (002) lattice plane in parallel to the interface. AlN is fully compatible with diamond in mechanical matching (e.g. thermal expansion rate) and chemical joining (e.g. covalent bonding coupling). Moreover, its (002) plane is closely similar to (111) face of diamond lattice. In essence, the oriented AlN coating has transformed polycrystalline diamond grains in volume into a single crystal plane on surface. Such an orientation transformation creates an ideal buffer layer for epitaxial deposition of Si, SiC, GaN, InN, GaAs or other semiconductors. Consequently, Kinik' DiAlN® wafers are suitable to make next generation ULSI, LD, LED, MW devices that are capable to operate with excessive power and frequency.

In addition to for making future information processing devices, the DiAlN wafer is well suited as communication message interfaces with power and frequency dwarfing the current designs. For example, AlN is piezo-electric so it can convert electromagnetic signal into sound wave, and vice versa. Consequently, DiAlN substrate can be an efficient surface acoustic wave (SAW) filters that are indispensable for receiving and transmitting wireless signals. Unlike current ceramic SAW filters (e.g. $LiTiO_3$, $LiNbO_3$) that are thermal insulator and ionic conductor that will build up heat and leak out electricity, DiAlN is thermal conductor and electrical resistor so it can handle much higher frequency (e.g. >10 GHz) and power (e.g. Kw) that can burn out instantly the current designs of ceramic filters used in cell phones and other wireless communication devices.

In summary, DiAlN wafers are a cost effective solution for epitaxial deposition of sophisticate semiconductors and for piezo-electrical transmission of electromagnetic signals. The implementation of DiAlN substrate on the commercial scale will usher our way into the next 3C (computer, communication, consumer) and 3G (third generation of design) society that is based on the efficiency of knowledge integration.